

From minijet saturation to global observables in $A + A$ collisions at the LHC and RHIC

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Abstract

We review the recent results from the computation of saturated next-to-leading order perturbative QCD minijet initial conditions combined with viscous hydrodynamical evolution of ultrarelativistic heavy-ion collisions at the LHC and RHIC. Comparison with experimental data is shown.

Keywords: heavy-ion collisions, initial state, minijets, perturbative QCD

1. Introduction

In this proceedings we report the results from our recent study [1], where we have computed the local initial energy densities and formation times of the produced quark-gluon plasma (QGP) for the fluid-dynamical evolution in ultrarelativistic heavy-ion collisions at the LHC and RHIC. The basis of the framework is a rigorous next-to-leading order (NLO) perturbative QCD (pQCD) minijet transverse energy (E_T) calculation using the latest nuclear parton distribution functions [2, 3]. The production of the initial energy is then assumed to be moderated by gluon saturation.

By using viscous hydrodynamics, we show that we can obtain a good simultaneous description of the centrality dependence of multiplicity, transverse momentum (p_T) spectra and elliptic flow (v_2) measured in Au+Au collisions at RHIC and Pb+Pb collisions at the LHC. In particular, the shear viscosity in the different phases of QCD matter is constrained in this framework simultaneously by all these data.

2. Model setup and results

The saturation criterion for the minijet E_T production in $A+A$ collision at non-zero impact parameters, is formulated as [1]

$$\frac{dE_T}{d^2\mathbf{s}}(p_0, \sqrt{s_{NN}}, \Delta y, \mathbf{s}, \mathbf{b}, \beta) = \frac{K_{\text{sat}}}{\pi} p_0^3 \Delta y, \quad (1)$$

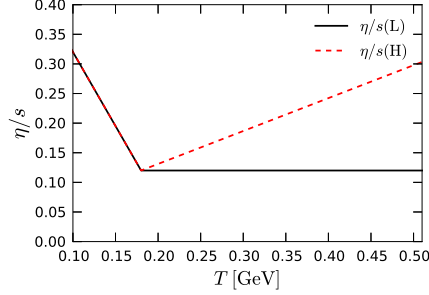


Figure 1: (Color online) The parametrizations "L" and "H" of the shear viscosity to entropy density ratio. From [1].

where $dE_T/d^2\mathbf{s}$ is the computed minijet E_T above a p_T scale p_0 , produced into a rapidity region $\Delta y = 1$ at an impact parameter \mathbf{b} . Here K_{sat} is an unknown proportionality constant of the order of $\mathcal{O}(1)$, \mathbf{s} is the transverse position and $\sqrt{s_{NN}}$ is the cms-energy in the collision. As discussed in [1, 4], the parameter $\beta \in [0, 1]$ controls the soft pQCD kinematics inside the acceptance window Δy . Once the solution $p_0 = p_{\text{sat}}$ of the transversally local saturation criterion, Eq. (1), is known for given K_{sat} and β , the local energy density is obtained as

$$\epsilon(\mathbf{s}, \tau_s) = \frac{dE_T}{d^2\mathbf{s} \tau_s \Delta y} = \frac{K_{\text{sat}}}{\pi} p_{\text{sat}}^4, \quad (2)$$

where the local formation time is $\tau_s = 1/p_{\text{sat}}$. Note that the formation time τ_s is different at different points in the transverse plane. However, for the hydrodynamical evolution, we need the initial state at a fixed τ_0 . The prethermal evolution from τ_s to $\tau_0 = \frac{1}{1 \text{ GeV}} \simeq 0.2 \text{ fm}$ is obtained using either Bjorken free streaming (FS) or the Bjorken hydrodynamic scaling solution (BJ). For more details see Ref. [1].

For the hydrodynamical evolution, we take the 2+1 D setup introduced in [5]. We use the lattice QCD and hadron resonance gas based equation of state s95p-PCE-v1 [6] with a chemical freeze-out temperature $T_{\text{chem}} = 175 \text{ MeV}$. The kinetic freeze-out temperature is here always $T_{\text{dec}} = 100 \text{ MeV}$. The parametrizations of the temperature-dependent shear viscosity to entropy ratio $\eta/s(T)$, for which we show the following results, are shown in Fig. 1. The shear-stress and transverse flow are initially set to zero.

In Fig. 2a and 2b we show the computed centrality dependence of the charged hadron multiplicity in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$ and in Au+Au collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$ compared with the ALICE [7], PHENIX [8] and STAR [9] data. For a given set of parameters $\{\beta, \text{BJ/FS}, \eta/s(T)\}$ the remaining parameter K_{sat} is tuned such that the multiplicity in the 0-5% most central collisions at the LHC is reproduced. Next, the obtained centrality dependence of the computed p_T -spectra of charged hadrons are shown in Fig. 2c for the LHC and in Fig. 2d for RHIC. The data are from [10] and [11, 12], correspondingly.

Finally, in Figs. 2e and 2f we show the elliptic flow coefficients $v_2(p_T)$ at the LHC and RHIC, respectively. The data are from [13] (ALICE) and [14] (STAR).

To conclude, we note the following: the p_T spectra are not very sensitive to the parameters $\{\beta, \text{BJ/FS}, \eta/s(T)\}$ once the centrality dependence of the multiplicities is under control. The v_n coefficients, however, depend strongly on the $\eta/s(T)$ parametrization: an ideal fluid description would fail to reproduce the measured $v_2(p_T)$, while with both the "L" and "H" parametrizations we get a good agreement with the data. Before entering a more complete global analysis for $\eta/s(T)$, the initial event-by-event density fluctuations need to be considered in this framework. This is a work in progress.

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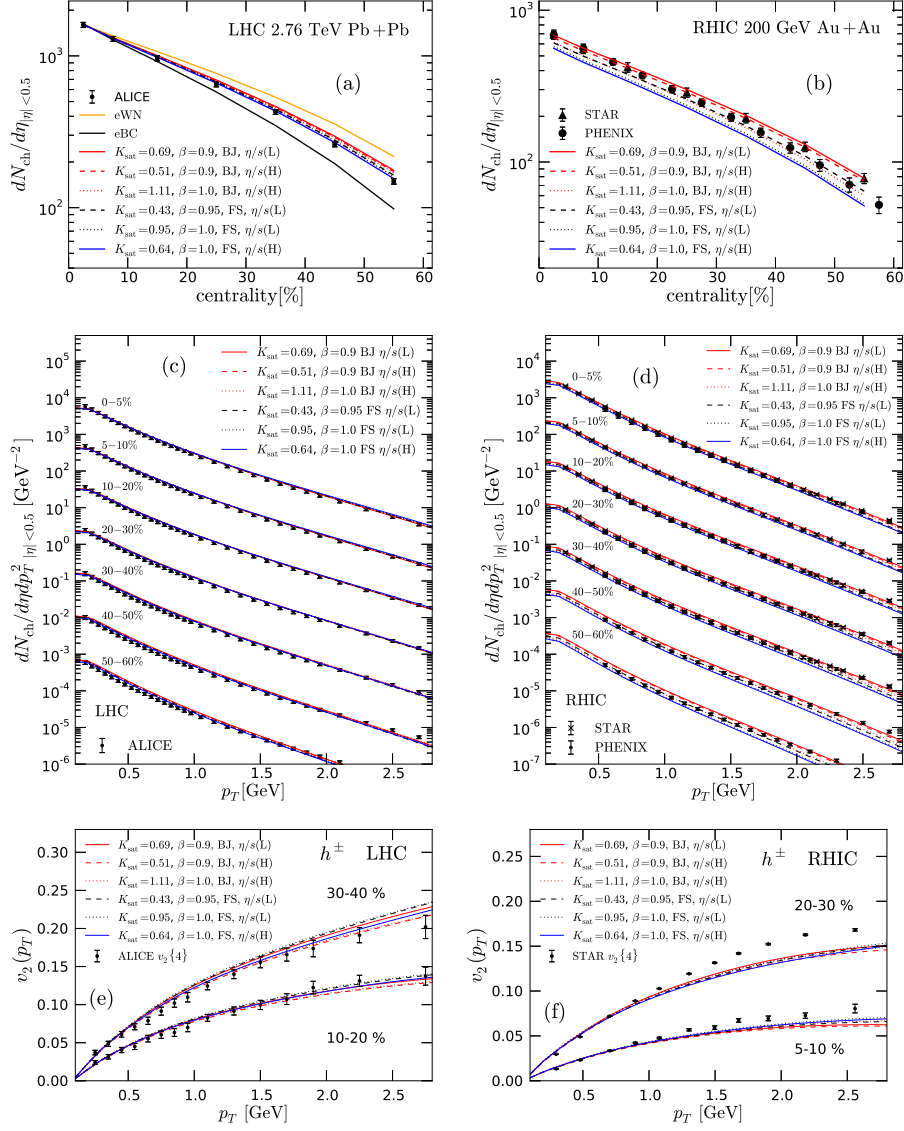


Figure 2: (Color online) Centrality dependence of the charged hadron multiplicity at the LHC (a) and RHIC (b). p_T spectra of charged hadrons at the LHC (c) and RHIC (d), in the same centrality classes as the ALICE data in panel (a), and scaled down by increasing powers of 10. Elliptic flow coefficients $v_2(p_T)$ at the LHC (e) and RHIC (f), compared with the measured 4-particle cumulant $v_2\{4\}(p_T)$. Labeling of the theory curves in each panel is identical, and the parameter sets $\{K_{\text{sat}}, \beta, \text{BJ/FS}, \eta/s(T)\}$ are indicated. The labels H and L refer to Fig. 1. From [1].